NPS-57Bp74031

NAVAL POSTGRADUATE SCHOOL

Monterey, California

PREDICTION OF THE RESPONSE OF THE EXIT WALL OF THE NWC 50 CUBIC FEET TANK TO HYDRAULIC RAM

R. E. BALL

MARCH 1974

Interim Report for Period 1 July 1973 - 30 June 1974

epared for:
val Weapons Center
na Lake, California 93555

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Rear Admiral I. W. Linder
Superintendent

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Provost

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-57Bp74031	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PREDICTION OF THE RESPONSE OF THE EXIT WALL OF THE NWC 50 CUBIC FEET TANK TO HYDRAULIC RAM		5. TYPE OF REPORT & PERIOD COVERED Interim Report 1 July 1973 - 30 June 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. E. Ball		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940 Code 57Bp		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N6053075 PO00011
11. CONTROLLING OFFICE NAME AND ADDRESS NAVAL WEAPONS CENTER CHINA LAKE, CALIFORNIA 93555		12. REPORT DATE March 1974
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Naval Weapons Center is conducting a series of hydraulic ram effects tests on simulated fuel tanks. 12.7mm API projectiles are fired at a fluid-filled rectangular tank with a streched rubber membrane entry wall and a thin 20 inch x 20 inch aluminum exit wall. The computer code SATANS has been used, in conjunction with the NWC code for the fluid pressure, to predict the response of the exit wall to the passage of the 12.7mm projectiles. This report presents the computer results.

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S/N 0102-014-6601

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1. Introduction

Mr. Wallace Fung (Code 5114) is conducting a series of hydraulic ram effects tests at the Naval Weapons Center, China Lake, California. These tests involve firing 12.7mm API ballistic projectiles at a fluid-filled rectangular tank. The tank is 60 inches wide by 60 inches high, with 22 inches between the entry and exit walls. The entry wall is a stretched rubber membrane. The center portion of the exit wall is a 20 inch by 20 inch 2024-T3 aluminum plate clamped to a 0.25 inch steel wall. Two thicknesses of the aluminum plate are considered; 0.063 inches and 0.125 inches. The top of the tank is open. The 12.7mm projectiles are fired at the tank with velocities between 1300 fps and 2900 fps. The low velocity projectiles cause some bulging of the exit wall accompanied by short cracks of the order of one inch in length. The high velocity projectiles cause severe tearing of the wall with several cracks running from the exit hole to the edges of the plate.

2. Investigation

The computer code SATANS has been used, in conjuction with the NWC computer code developed by Lundstrom, to predict the response of the exit wall to the passage of the 12.7mm projectiles. The code SATANS can compute the geometrically nonlinear, elastic, transient response of a circular plate to an arbitrary pressure. The code has been modified to account for the fluid-structure interaction phenomenon using the piston theory.* The NWC code computes the fluid pressure and motion throughout a rectangular volume due to a ballistic API projectile. It provides the input pressure data to SATANS, which then computes the wall response.

*For a more detailed discussion of SATANS and the piston theory, refer to Ref. a.

Predictions of exit wall axisymmetric motion due to hydraulic ram have been carried out for a 20 inch diameter aluminum circular plate 0.063 inches thick. Two edge support conditions were considered; 1) restraint against all translation and rotation and 2) restraint only against normal deflection. Finite difference stations were spaced at intervals of 0.2 inches over the radius of plate. The input parameters to the NWC code (version one, mod one) for the 12.7mm projectile at 2797.5 fps were:

EN	=	3.00000						
BS	=	0.60000						
EFRACT	=	3.00000						
NCTUM	=	1						
NSTRIP	=	0						
NT	=	1						
XTUM	=	6.00000						
DXTUM	=	9.00000						
XSTRIP	=	35.00000						
XMASS(3)	=	0.10660	0.06410	0.04250				
AREA(6)	=	0.20460	1.03780	0.14320	0.70020	1.03780	0.08550	
DRAG(6)	=	0.05000	0.30000	0.05000	0.30000	1.00000	0.82000	
BETA(7)	=	0.00173	0.05272	0.00202	0.05915	0.44076	0.01187	0.01974
VEL	=	2797.50000						
DENS	=	0.03610						
PO	=	14.70000						
PC	=	0.0						
C	=	4915.00000						
BC	=	0.29400						

The entry point and the exit point were taken at the center of each wall, i.e., the center of the circular plate. The results for the incident fluid pressure at the exit wall and ρc times the velocity normal to the exit wall at radial intervals of 0.2 inches were punched on cards for every 5 μsec*. These cards were used as pressure input data to SATANS, thus providing the wall pressure data as a function of space and time.

*In piston theory the pressure on the structure is $p_i + \rho c v_i$ where p_i is the incident pressure, ρ is the fluid density and c is the sonic velocity.

3. Results

The results for the incident pressure p_i and the piston theory pressure $p_i + \rho c v_i$ at the exit wall are plotted in Fig. 1 as a function of radial distance from the exit point at time t = 715 μsec. The projectile exits the tank at t = 741.8 μsec. Note the large concentration of pressure in the vicinity of the exit point.

The results for the normal deflection of the clamped exit wall are plotted in Fig. 2 as a function of distance from the exit point for t = 715 μsec and t = 990 μsec. Note that the scale for t = 990 μsec starts at 0.10 inches for convenience in plotting the data. Note also the large bulge in the plate near the exit point.

The outersurface (dry side) radial stress at the exit point of the clamped plate is plotted as a function of time in Fig. 3. Note the rapid buildup of stress from t = 665 μsec to t = 765 μsec. The stress exceeds the 0.2% offset yield stress of 2024-T3 at t = 720 μsec and the ultimate tensile yield stress at t = 725 μsec. Of course the results past t = 720 μsec are not valid because they do not account for plasticity. The material at the center of the plate will yield and crack, and the surrounding plate material will carry the applied load. Thus, the stresses in the surrounding material will probably be larger than the elastic analysis indicates. Even though the analysis is not valid for t = 720 μsec it does indicate that very large stresses will occur, probably accompanied by large cracks.

Plots of the clamped plate outersurface (dry side) radial stress as a function of the distance from the exit point are plotted in Fig. 4 for t = 715 μsec and t = 990 μsec. Figure 5 contains the same results for the simply supported plate. Note the very large stresses over the center inch of the plate in both figures. Also note the large stresses near the outer edge in both figures.

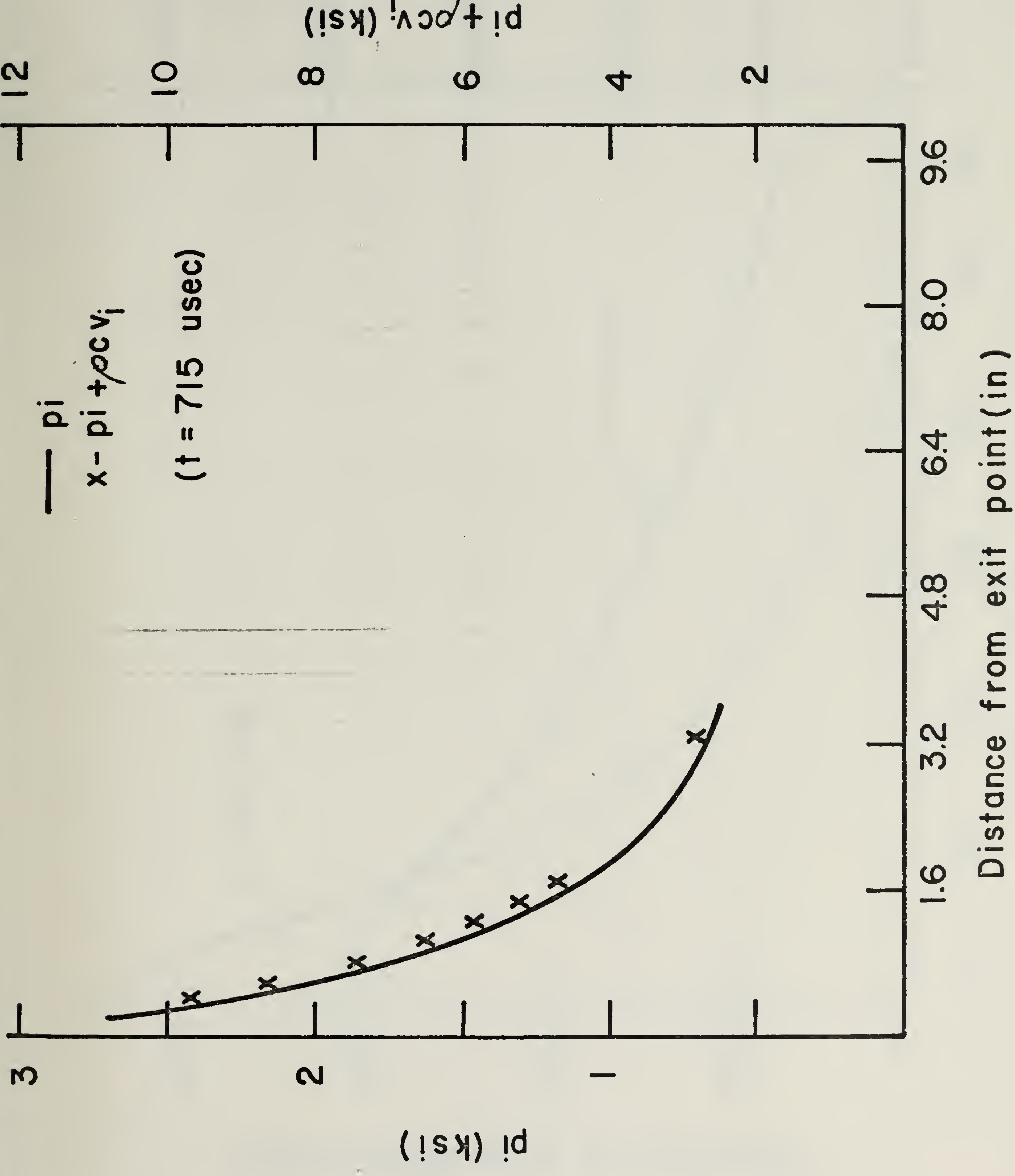

Figure 1 pi and pi + $\rho c v_i$ versus radial distance from exit point

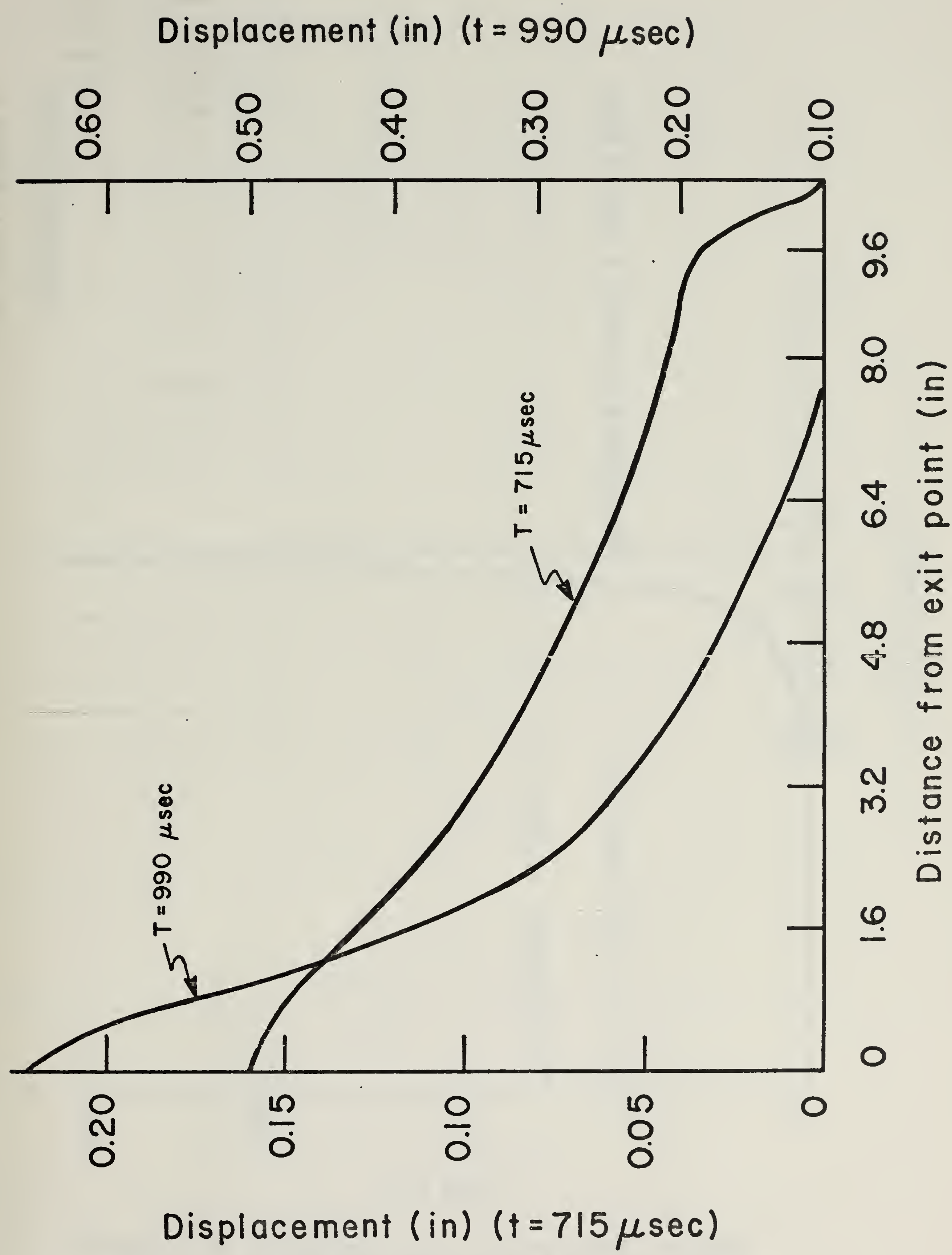

Figure 2. Wall displacement at t = 715 and 990 μsec, clamped plate.

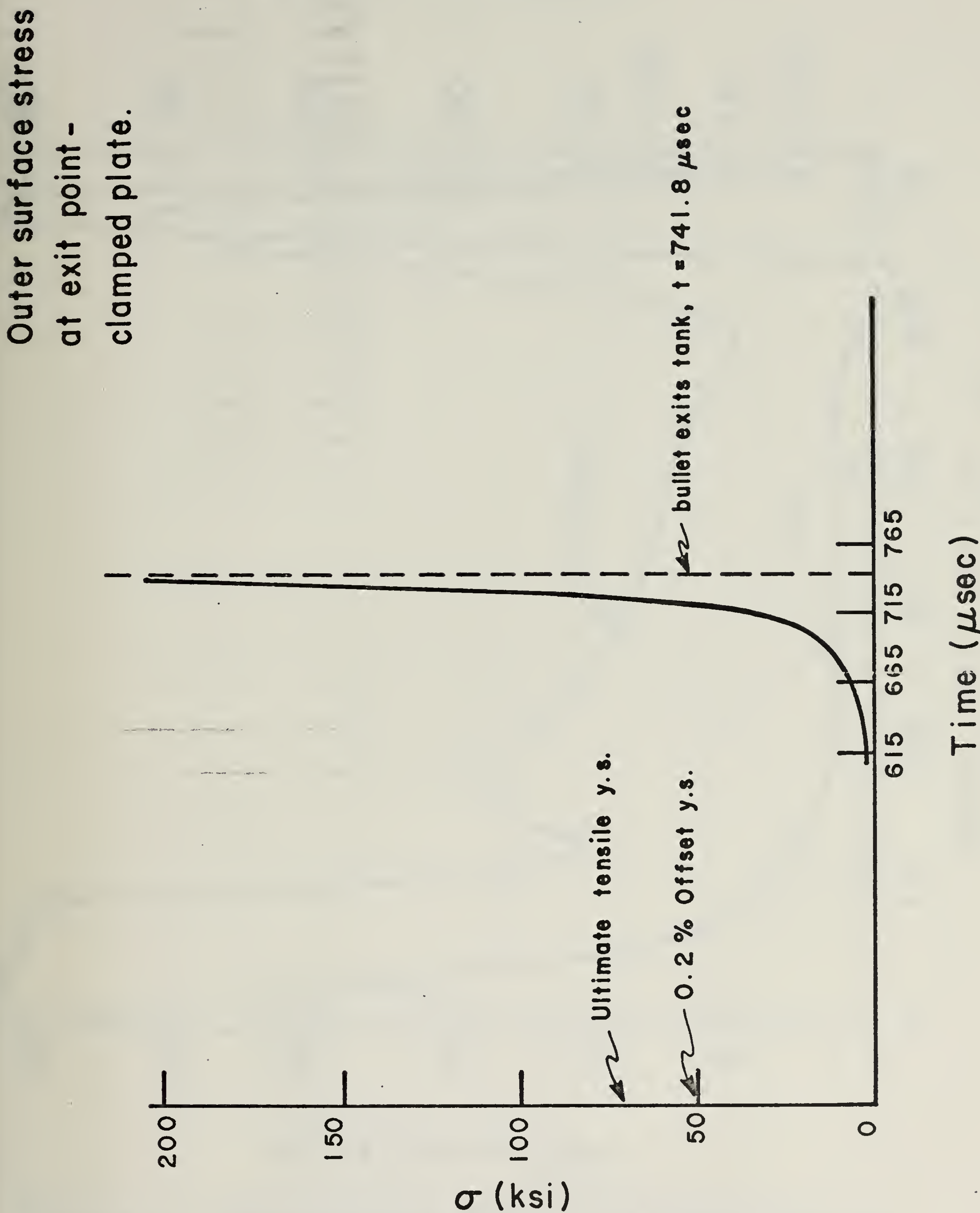

Figure 3. Outersurface (dry side) radial stress at exit point, clamped plate.

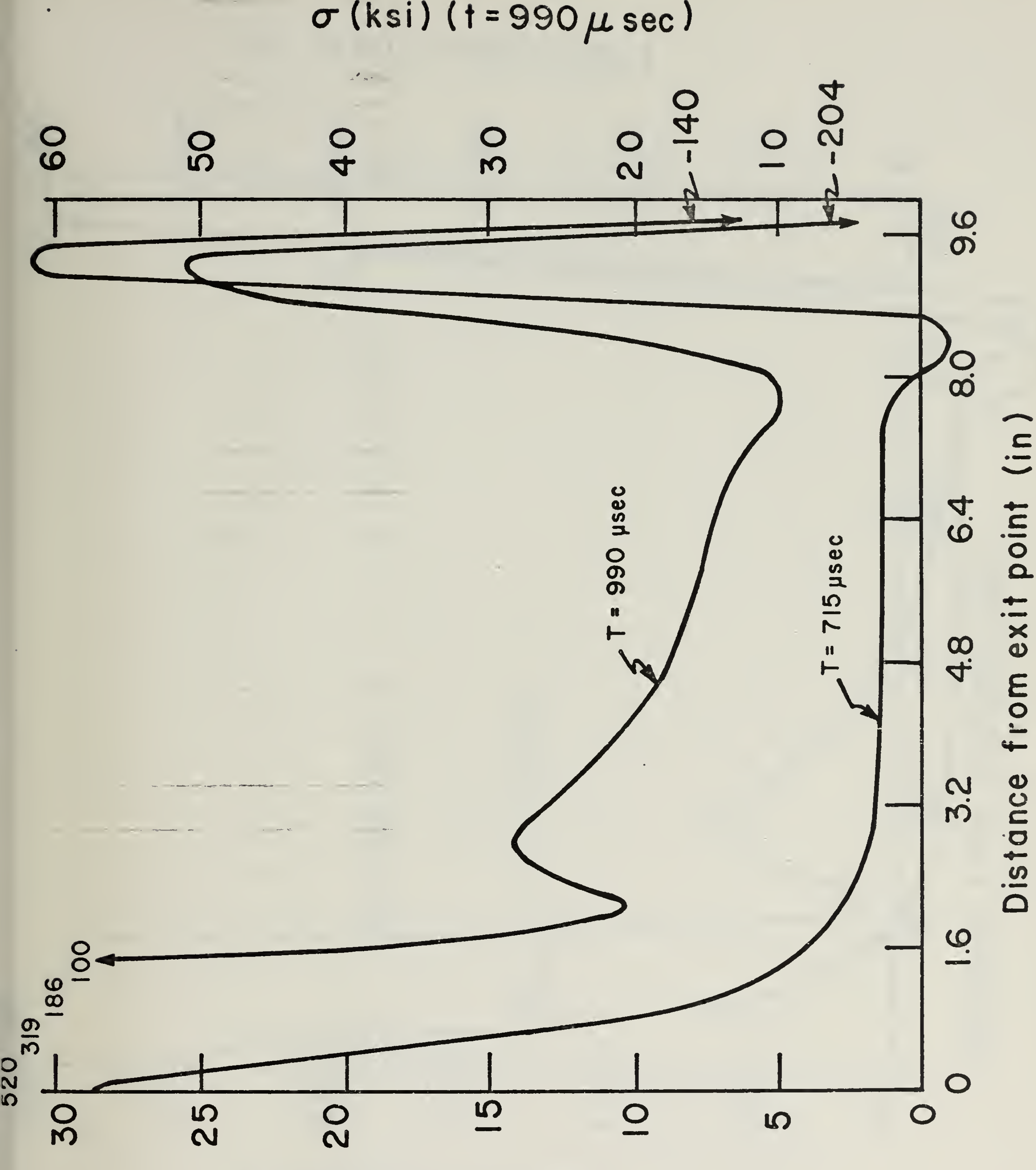

Figure 4. Outersurface (dry side) radial stress at t = 715 and 990 μsec, clamped plate.

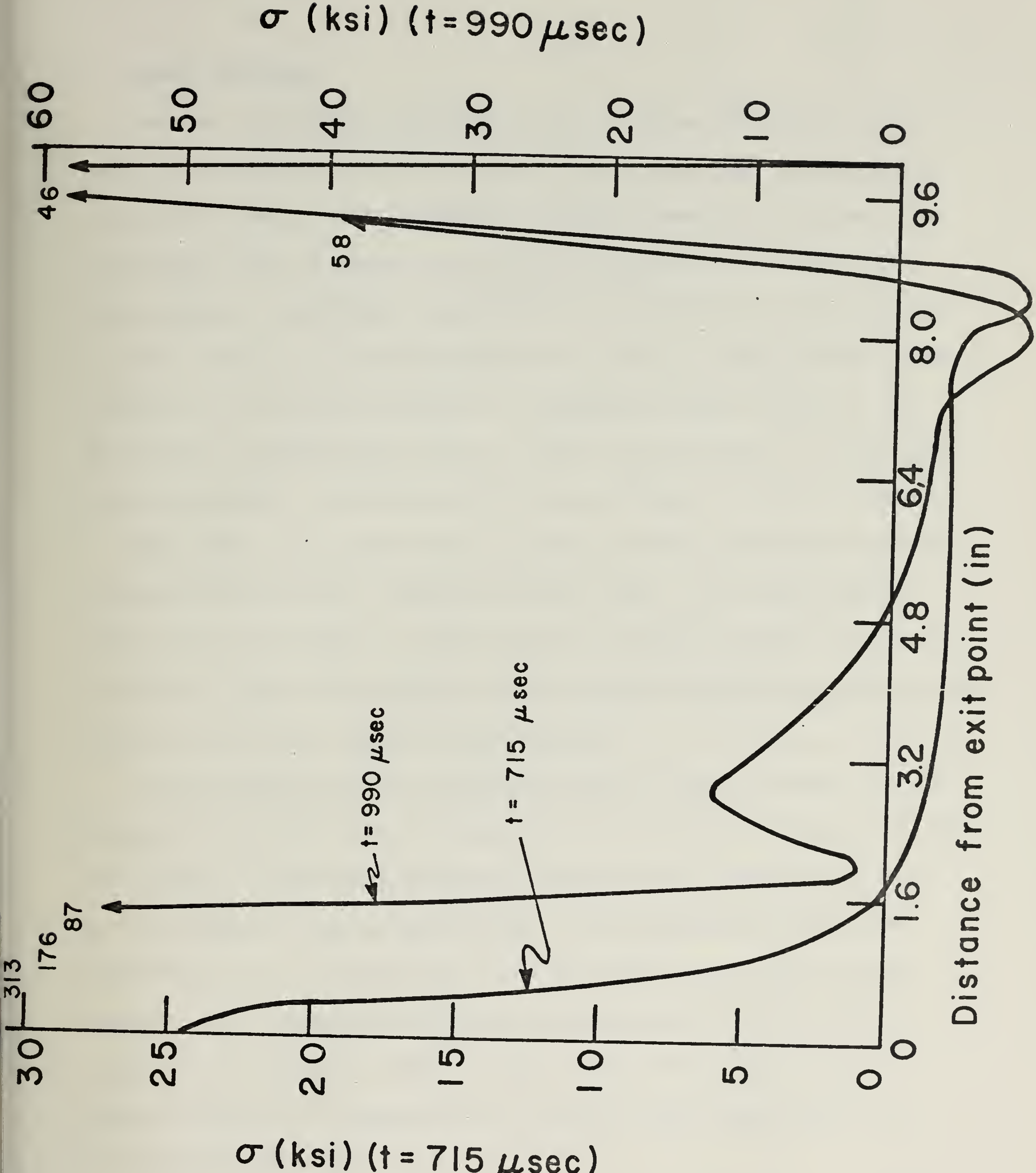

Figure 5 Outersurface (dry side) radial stress at $t=715$ and 990 μsec, simply supported plate.

4. Damage Mechanism

We offer the following explanation as a possible description of the hydraulic ram effect on the exit wall. As the projectile passes through the fluid it causes large stresses to propagate ahead of it and sets the surrounding fluid in motion in the general direction of the exit wall. This loading is essentially concentrated in the vicinity of the projectile as shown in Fig. 1. As the projectile nears the exit wall the wall bulges locally due to the fluid pressure and momentum as shown in Fig. 2. If the loading is sufficiently large the plate may crack prior to penetration by the projectile. As the projectile passes through the wall the loading, if large enough, can cause further cracking and the plate petals outward, each petal acting like a cantilever beam or plate. This large opening allows some of the fluid to escape and the subsequent loading on the wall is reduced. Very little bulging out of the wall is expected, mostly severe petaling, due to the large hole that occurs.

If the loading ahead of the bullet is not as large, the plate may not crack prior to penetration, but may yield, thus causing a bulge around the exit point. As the bullet penetrates the plate some cracking will occur, but not enough to cause gross petaling. The loading on the wall after penetration is not relieved due to the fact that only a small hole was created. This subsequent loading may cause the plate to yield over a large area of the wall. Thus, the final shape of the wall may be an outward bulge over a large portion of the wall with a small hole near the center of the bulge.

If the loading is smaller than the two cases described above, only a small exit hole may occur, with either a small local bulge in the neighborhood of the hole, or perhaps no bulge at all.

If this mechanism is the correct one for the conditions we have considered we can conclude that the entry wall may not be as severely damaged as the exit wall due to the fact that the fluid is not moving toward that wall. The shock phase of hydraulic ram can add to the entry wall damage, but its effect is usually localized near the entry point. The non-exit walls will also not be as severly damaged for the same reason. However, design or construction defects such as stress concentration may cause local damage in the non-exit walls such as cracking at rivets or stiffener-skin junctions.

5. Conclusions

The computer results indicate severe damage will occur in the 0.063 inch exit wall due to the 12.7mm projectile traveling at approximately 2800 fps. This prediction is born out by preliminary NWC tests which showed that severe cracks were caused in the exit wall under these conditions. A description of the response is offered as a possible explanation for the damage associated with hydraulic ram.

6. References

a. Fuhs, A. E., Ball, R. E, and Power, H. L., "FY 73 Hydraulic Ram Studies", Naval Postgraduate School, NPS-57FU74021, Feb. 1974.

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